Seasonal and situational impacts on the effectiveness of a decentralized stormwater management program in the reduction of runoff volume (Cincinnati OH; USA)

Impacts saisonniers et situationnels d'un programme de gestion décentralisée des eaux pluviales sur la réduction du volume des ruissellements (Cincinatti, Ohio, USA)

Shuster WD*; Morrison MA[b]; Thurston HW

Sustainable Environments Branch, ML498; National Risk Management Research Laboratory Office of Research and Development; United States Environmental Protection Agency 26 W. Martin Luther King Drive;Cincinnati,OH ;45268.p:513-569-7244;f:513-487-2511; shuster.william@epa.gov;*corresponding author
[b]Environmental Stressor Management Branch, Land Remediation and Pollution Control Division; National Risk Management Research Laboratory Office of Research and Development; United States Environmental Protection Agency 26 W. Martin Luther King Drive; Cincinnati, OH 45268.

RÉSUMÉ

Une approche décentralisée pour la gestion des eaux pluviales a été mise en œuvre dans le système d'assainissement d'une petite zone de banlieue sur la base d'une enchère inversée. Cette campagne a conduit à l'installation de 83 jardins pluviaux et 176 tonneaux de pluie, concernant approximativement 20% des 350 propriétés résidentielles du bassin versant. Il a été constaté un fort taux d'adoption (~ 50%) des jardins pluvieux et tonneaux de pluie (jusqu'à 4) dans une partie de cette zone. Nous avons étudié ce quartier pour déterminer comment ces pratiques pourraient réduire le volume des eaux pluviales et comment l'efficacité serait impactée par l'évolution de la déconnexion des surfaces imperméables des systèmes de gestion, et les effets saisonniers sur l'aspect pratique et fonctionnel comparatif entre les jardins et les tonneaux. Les effets saisonniers ont été négligeables pour les jardins pluviaux (qui ont conservé leur capacité de rétention en toutes saisons). Les tonneaux de pluie ont joué un rôle plus mineur en raison de leur relativement faible volume de rétention, bien que cette pratique offre apparemment d'autres avantages non-structurels. Nous avons constaté que l'engagement des propriétaires qui déconnectent de grandes étendues de surface imperméable était crucial pour une efficacité optimale de ces programmes.

ABSTRACT

A decentralized, retrofit approach to storm water management was implemented in a small suburban drainage on the basis of a voluntary reverse auction. This campaign led to the installation of 83 rain gardens and 176 rain barrels on approximately 20 percent of 350 residential properties in the watershed. One area of the drainage showed unusually high (~50%) adoption of the rain garden and rain barrels (up to four) that were offered. We studied this neighborhood for the potential of these practices to reduce stormwater volume and how effectiveness would be modulated by changes in connectivity of impervious surface to the management practices, and seasonal impacts on the comparative practicality and function amongst the gardens and barrels. Seasonal impacts were negligible for rain gardens (which maintained detention capacity across the seasons). Rain barrels played a more minor role due to the relatively small amount of detention that they offer, although this management practice apparently offered other non-structural benefits. We found that landowner engagement in disconnecting larger extents of impervious surface would be critical in making this sort of program most effective.

KEYWORDS

Decentralized runoff management; rain garden; rain barrel; urban runoff; stormwater detention

1 INTRODUCTION

Due to the removal of losses (e.g., interception, infiltration) from the local water budget, urban societies have to contend with increased excess stormwater runoff volume (Booth and Jackson 1997; Villareal and Bengtsson 2004). The resulting large volumes of runoff have been historically dealt with through flow conveyance in pipes leading to streams or to wastewater treatment plants. In addition, stormwater conveyance systems have been designed as combined systems or with separate storm and septic sewers. In either case, the centralized arrangement of stormwater control has led to an infrastructure that degrades the environment in several different ways. Stream ecosystems are degraded through the delivery of unnatural volumes of stormwater within short time periods (a phenomenon known as flashiness) that erode riparian areas, incise the streambed which detaches the stream system from the flood plane, and these physical impacts otherwise destroy biological integrity of the stream ecosystem. Where septic and storm runoff flows are combined, high runoff volume during even modest precipitation events can activate both combined and septic sewer overflows, which are responsible for a great deal of water pollution due to the subsequent enrichment of stormwater volume with high nutrient and microbial (e.g., pathogenic bacteria) loads.

In the context of ageing infrastructure, decreased public investment (a trend that is being reversed in current times) in wastewater infrastructure, and unanticipated development leading to overburdened combined and septic-separate systems, the centralized management of wastewater often falls short in terms of public health and environmental quality objectives. From a municipal perspective, the impacts of centralized stormwater management can be substantial and very expensive to deal with. Some examples are soil loss from to eroded stream and riparian systems and the intensification of failure modes for overburdened. One way of dealing with the problems brought on by centralized stormwater management is to decentralize management efforts by implementing controls that are spread out through the drainage area, scaled to more closely match the scale of the stressor or disturbance, and therefore mitigates against the problem of having increasingly large volumes of water to manage at downstream locations (Parikh et al. 2005; Gilroy and McCuen 2009). In more general terms, this approach involves creating hydrologic losses higher in the catchment so as to reverse the urban hydrologic cycle from a net runoff producer to a net sink through infiltration or other types of detention of precipitation.

Storm flows from smaller drainage areas likewise have smaller volume and less momentum, and may therefore make these local flows more tractable for mitigation or treatment, opening up a larger suite of candidate management practices. We speculated that the residential parcel may offer an appropriate venue to apply source stormwater runoff controls. The impervious surface of a typical residential home is directly connected to stormwater system conveyances through gutters, downspouts and underground piping. The parcel also typically has a resident that occupies the dwelling, and therefore there is potential that the resident can be induced to act as an environmental manager by employing passive stormwater management practices and decrease parcel contribution to total catchment storm runoff volume. Two simple ways of creating losses in the suburban or parcel scale water budget are: rain barrels which store and temporarily detain a fixed amount of stormwater for later use (Vaes and Berlamont 2001); and rain gardens which are patches in the landscape that can provide an enhanced level of infiltration capacity that is both functional and aesthetically pleasing. Furthermore, these practices are easily scalable to the size of a typical parcel, as rain barrels can be added in series or parallel as needed; and rain gardens can be made larger - though not necessarily deeper (due to unfavorable subsoil hydraulics) - if topography or available lawn surface area is an issue. The current ground-swell of interest and investment in systems of decentralized stormwater management has often incorporated rain barrels and rain gardens into homeowner stormwater management programs. However, these management practices can have ranges of effectiveness that vary with time of year (i.e., climate) and how much impervious area is routed to the practice.

Our experimental work centered on a small urbanized watershed (Shepherd Creek, Cincinnati OH, USA) where we set up a field study to understand the extent to which economic incentives could effectively recruit homeowner stormwater managers through voluntary acceptance of on-lot, retrofit stormwater detention practices (rain gardens, rain barrels). Furthermore, we also asked whether this would lead to a decrease in stormwater runoff quantity and subsequent improvement in other metrics of environmental quality. The specific objectives of this paper are to determine where adoption rates were highest, use a model to understand how our management approach may alter the local hydrologic cycle towards a reduction in runoff; and discuss the situational and seasonal factors that may have affected the effectiveness of rain gardens and rain barrels.

2 METHODS

2.1 Project setting and monitoring

The Shepherd Creek catchment (Figure 1) in Cincinnati, OH (USA) drains approximately 1.8 km^2, and its lithology is primarily set in calcareous shale and limestone. Soils are predominantly silt loam and silty clay loam set on moderate slopes, and native soils have relatively slow infiltration rates and capacities. Residential areas flank the sides of the catchment with newer 1980s development on the west, and older 1960s housing on the east side. The impervious surface in these residential areas (predominantly rooftops and driveways (Roy and Shuster 2008)) and the transportation surfaces that connect these neighborhoods produce the large proportion of direct runoff in this catchment. This runoff is routed to stormwater outfalls, which outlet to tributaries that flow through downstream riparian areas that are subject to a wide variety of management, including riparian forest, equestrian trails, and managed lawns or meadows associated with other, more widely-dispersed residential dwellings.

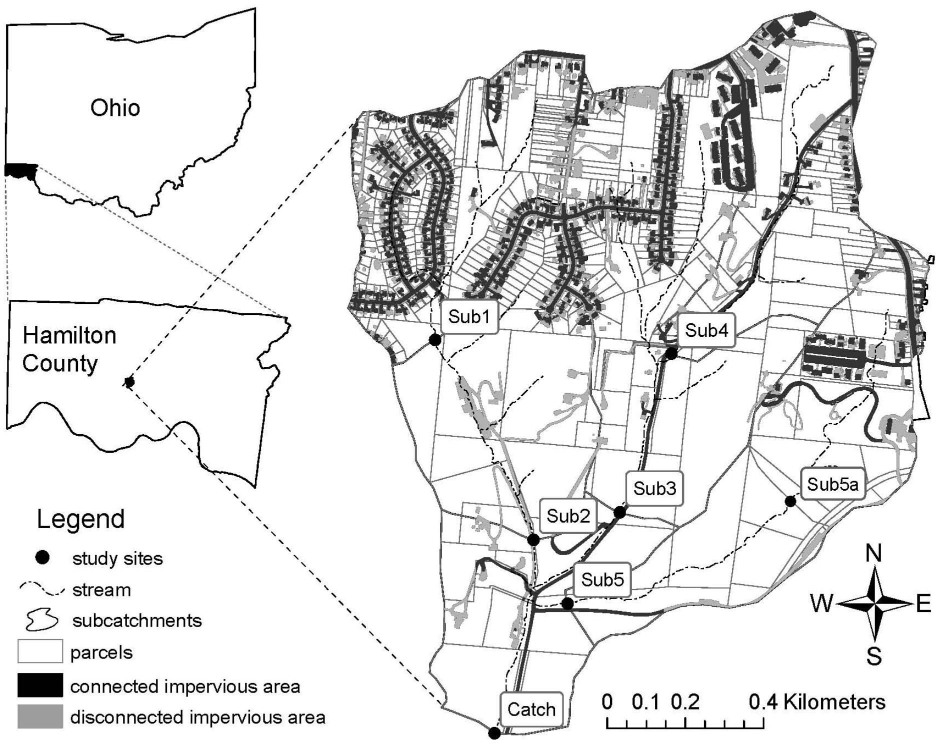

Figure 1. A diagram of the study site with both natural and urban attributes. Adapted from Thurston et al. (2008).

Our experimental design is composed of four treatment subcatchments (Sub 1, 2, 3, and Catch; with three monitored microcatchments at the stormwater outfall scale); and two reference-control catchments to constitute a nominal before-after, control-impact experimental design (see Green 1993). A city park on the east side of the watershed functions as a more or less a natural reference-control subcatchment in this study (Figure 1; Sub5) and an urban control-reference drainage area (Figure 1; Sub 4) lies in the northeast corner of the catchment. Parcel land use in the developed areas of the study catchment was surveyed by Roy and Shuster (2009) and it was determined that the median parcel area for impervious area was 210 m^2, which was distributed as 106 m^2 of directly-connected impervious area (that which has a piped connection to the storm sewer or stream reach), and 104 m^2 of disconnected impervious area. We assumed that the disconnected impervious area historically and presently drained to pervious areas, and therefore did not present a management imperative. Our experimental approach involved a comprehensive monitoring program that includes hydrometry, water chemistry, and biological resource-habitat assessments. In order to document environmental change due to management practices, we gathered three years of watershed data before practices were installed, and will continue to monitor through the early summer of 2011.

Specifically, we have monitored for daily average discharge at the catchment (Figure 1; Catch) scale, and 5-minute discharge at the subcatchment scale, then sub-minute discharge measurements at the microcatchment or neighborhood stormwater outfall scale. Discharge data is complemented by water quality samplings conducted in each of the drainages on a synoptic monthly schedule, with additional opportunistic storm samplings. We have sampled stream macroinvertebrate and periphyton communities and assessed riparian and headwater habitat quality at the subcatchment level every 6 weeks in the period April through October of each year. For nine residential homes that have both rain gardens and rain barrels, we monitor for the effectiveness of these practices. We monitor storage and usage patterns (via a levelogger) in this subset of rain barrels, and account for water balance with electronic soil water content measurement apparatus at four depths in eight representative rain gardens. We have worked with the local wastewater authority to obtain 5-minute rainfall data that is derived from NEXRAD or WSR-88 weather surveillence radar, and we selected the pixel that is specific to the neighborhood microcatchment (code number: 57341, www.msdgc.org) that is the focus of this study.

2.2 Administration of economic incentives

We recruited homeowners to actively participate in stormwater management through successive voluntary reverse auctions held in 2007 and 2008. Homeowners who chose to participate in the auction bid the amount that they feel is appropriate for any lost opportunity or compensation (e.g., for land taken occupied by the stormwater management practices) that they would require to have a rain garden or rain barrels placed on their property. A procurement auction was used in this study, and it was similar to the types of auctions currently being used by governmental agencies for the purposes of land conservation. We determined a base total amount of money to fund the auction, and payment for stormwater management practices and other costs were allocated until the funding was exhausted. Importantly, all homeowners within the study area were provided a fair and equal opportunity to participate in the auction. Specifically, we employed sealed bid, first price, discriminative price auction, where bids are further tempered by the environmental weighting index. The auction was designed to draw out the actual opportunity cost of stormwater management practice adoption. All eligible participants received background information (described below) and those wishing to adopt stormwater management practices submitted bids. The goal was to pay those landowners who adopt the most effective best management practices at the lowest price. The auction was run in the spring 2007and repeated in spring 2008, with each auction resulting in actual payouts and installations of rain gardens and rain barrels.

Potential participants received two direct mailings detailing the function and uses of the rain gardens and rain barrels, and the auction process. The first mailing included a cover letter and informational brochure, which was intended to notify the landowners in the watershed of the opportunity to participate in the Shepherd Creek project. The second mailing was sent out two weeks after the first and contained a cover letter, a copy of the informational brochure, an auction bid form, and a self-addressed, stamped envelope. All recipients also received nominal financial compensation ((US)$5) to encourage bidding and compensate homeowners for their time. In 2007, due to the novelty of the project, we used door hangers to inform homeowners of the forthcoming mailing. We also extended the auction for 2-3 weeks and sent an additional letter with another copy of the bid form. Homeowners were directed to the project website (www.mtairyraincatchers.org) or a contact phone number for additional information. In addition to the information mailed to homeowners, a demonstration rain barrel and two rain gardens were installed in Fall 2006 at the Mt. Airy Arboretum, a public park area within the Shepherd Creek watershed; the rain gardens had signage explaining the project and the stormwater management practices. To rank auction bids for stormwater management practices, we considered each eligible parcel's total impervious area, rooftop connectivity to sewer pipes, the predominant soil type, and distance from a stream. A landscape-level effectiveness metric was derived to account for both cost and environmental effectiveness so that bids could be ranked in ascending order to highlight prospective installations that would achieve highest efficiency with the funds available or such that the most inexpensive and highly effective implementations were selected first for implementation (Thurston et al. 2008). Beyond these objective criteria, there was also potential for bid refusal for any barrel or garden bid or proposed location outside of Shepherd Creek was not accepted.

2.3 Stormwater management practices

Two types of retrofit management practices were offered in the auction. A landowner could bid on up to four 284 L (75 gallon) rain barrels, a single 16 m^2 rain garden, or both practices. Rain barrels with screened tops were set under roof downspouts that had been shortened. The overflow outlet from each rain barrel was routed to either the household downspout drain for stormwater, but in some cases routed to the rain garden or pervious lawn space. Rain gardens were designed to occupy 16 m^2 of area and actual dimensions varied at installation depending on local conditions. The rain garden was a generic design proposed in Shuster et al (2008) that was based on assumptions of earlier estimates of median impervious surface and measured soil hydraulic properties. Soils were tilled with a walk-behind mini-excavator to an average depth of 0.5 m (under proper, reasonably dry soil moisture conditions to avoid sealing of perimeter walls), and amended with fine-milled peat moss and leaf compost to improve soil tilth and promote infiltration. Due to the heavy silt clay subsoils that are typical of this area, an underdrain (i.e., French drain, tile drain, etc.) was used in the majority of rain gardens to facilitate drainage of the rooting zone. Where an absence of slope in the local topography prevented placement of an underdrain outlet, rain gardens were excavated to have a deeper rooting zone (depth ~ 0.66 m), with the intent that the additional depth would provide additional infiltration capacity. The gardens were built to provide surface storage in 20 cm of depth formed by the surface bowl shape of the rain garden, and 5 cm of "freeboard" allowed by the berm surrounding the downslope of the rain garden. Capacity for excess stormwater runoff was 3.85 and 4.27 m^3 for gardens with and without underdrains, respectively. These capacities for rain gardens would translate to a volume capacity-to-directly-connected impervious surface area of approx. 0.04 m.

Figure 2. (left, a) shows a typical rain garden installation at inception of the warm season (June 2008) in full-bloom. Direct runoff from parcel impervious area is routed overland to the rain garden. (right, b) shows two rain barrels as installed at a residence in the Shepherd Creek. The overflow drains were ultimately detached – by the homeowner – and allowed to run into the rain garden that is located in the back yard area, which is not visible in this photo.

2.4 Modeling approach

A single micro-catchment was used in this demonstration modeling exercise (see Figure 3). We used the USEPA Stormwater Management Model (SWMM; ver. 5-LID, Beta release version B) to develop a simple abstraction of catchment conditions and potential impacts of rain barrel and rain garden practices for small-volume rainfall pattern. In this newer conception of SWMM, we created parameter sets for each stormwater management practice, and could then implemented these practices into the model. The overall subcatchment size was estimated at 3.6 ha and all dimensions were taken from a field-verified geospatial database. The flow width was taken as the leading edge of flow approaching the street from both sides of the catchment, which was approximately 330m. Impervious area was estimated to be 18% of the catchment, and was composed of rooftops and house footprint (0.33 ha), driveways and sidewalks (0.08 ha), and the roadway itself (0.23 ha). The majority of the drives, sidewalks, and roadways were directly connected to the stormwater sewer, and it was assumed that all rooftop area was directly connected to the stormflow conveyance as well. All flows were routed to an unrestricted outlet. The rainfall event had a cumulative depth of 0.2 cm, which is a relatively frequent depth of precipitation in this area, and used to demonstrate the capacity of the stormwater practices to absorb the rainfall event that is both the most frequent in the annual record, and therefore also of low depth. Calibration data from outfall stormflow discharge will not be available until mid-2010, at which time we will run the model in a calibrated mode. Rain gardens had generally unform area, similar soil depth (all had underdrains), an average infiltration rate of 3.5 cm hr^{-1} (measured by double-ring infiltrometry in 2008, n=78). Rain barrel design in SWMM was set such that a full barrel emptied in about one half-hour, the drainage rate through a ~2cm hose was nearly 250 cm hr^{-1}, and the overflow outlet was unrestricted. In a projection of how the use of public right-of-way may affect stormwater quantity, we employed a model of bioswales, which were composed of a sandy soil 45cm deep with a 20cm deep gravel underlayer that would drain to the subsoil layer, had a length-to-width ratio of 10 :1, and were conceived to fit between residential driveways.

3 RESULTS AND DISCUSSION

Based on the apparent success of the first voluntary auction in 2007 and consumer demand, a second voluntary auction was held in 2008. Overall, acceptance was higher than we expected; and for both auctions, nearly 50% of all auction participants entered a zero dollar bid for stormwater management practices. This rather “green” response indicated that no-cost stormwater management practices and their maintenance provided for three years constituted a sufficient incentive for citizens to engage in stormwater management. This was one aim of the auction approach, to determine how citizens would respond to this unique incentive. The large proportion of zero-dollar bids among the total number of bids was also an indication that costs for this type of program may be lower than expected. Yet, the bids that did require cash payout to citizens resulted in a relatively small amount as bid pay outs for rain gardens and rain barrels averaged (2008, US)$ 70.12 and 36.44, respectively (Thurston et al. 2008). The two auctions led to the installation of 83 rain gardens and 176 rain barrels onto more than 20% of the 350 residential properties in the Shepherd Creek catchment, and thereby affected about 6 ha of residential land, assuming an average parcel size of 800 m^2. Yet, the routing of stormwater to rain gardens and rain barrels was highly variable. This is in part due to the fact that we had to negotiate the final location of the rain garden with the landowner, and depending on this location relative to the dwelling and lawn geometry, there may be a predominance of either sheet flow, direct runoff from a downspout, or a combination of both types of flows.

The spatial distribution of stormwater management practices was uniform across the catchment (data not shown), though one micro-catchment area (29 houses; Figure 3) exhibited a higher landowner participation at a rate of ~50%, which led to a relatively high density of areas in management among other neighborhood stormwater outfall micro-catchments. In the case of this area (along Westonridge Dr), homeowners adopted as: 4, 3, 8, for the categories of rain barrels only, rain garden only, and both rain barrels and a rain garden, respectively. Accordingly, fourteen homeowners did not participate in the auction. The majority of the participating landowners were aggregated in the lower part of the micro-catchment. While this may indicate some degree of collusion amongst bidders, three of the participants in this lower section had successfully bid in 2007, which may indicate that this is not collusion and rather a case where early-adopters may have inspired neighbors to adopt later. On an anecdotal basis, we were informed that once homeowners found out that their neighbors had received free environmental management tools (and that this offer was not fraudulent), and actually saw the practices installed, the incentive may have been thereby more effective via this form of local marketing.

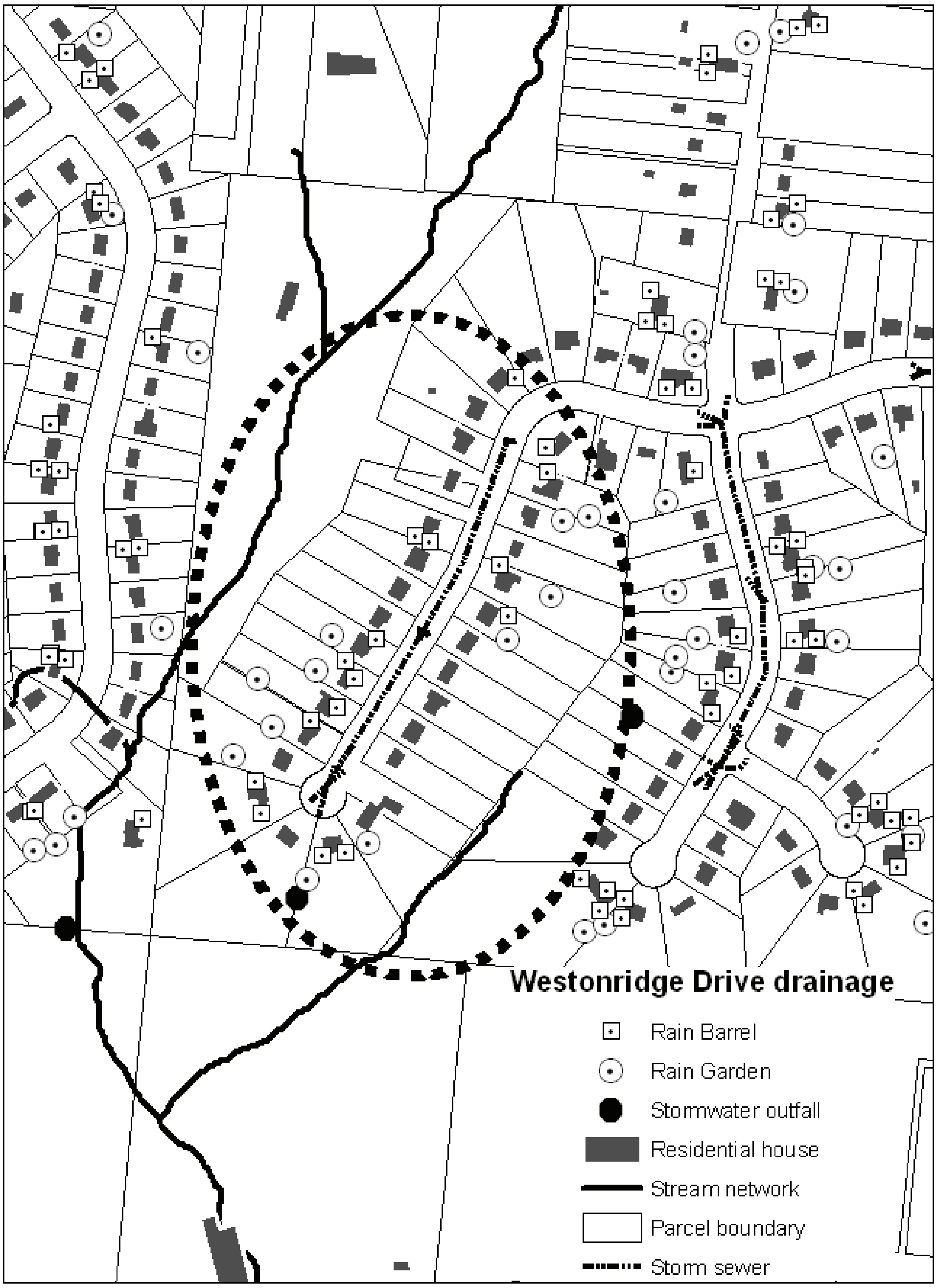

Figure 3. Diagram shows area of interest (within dashed oval area) and site details for a micro-catchment where the implementation of rain gardens and rain barrels was most dense.

We relied upon detention of stormwater by routing to a variety of sinks, which included available rain barrel volume; surface detention, infiltration (into available soil pore space) and redistribution of soil water in rain gardens, to subtract stormflow from stormwater pipes. There is a capacitative aspect to both rain gardens and rain barrels (Vaes and Berlamont 2001), wherein total capacity is maximized when the practice is in a dray state, which is not always the case, and so antecedent conditions plays a role in the detention capacity of any given practice. We look at effectiveness in more than one way though, and it was important to understand if any of the practices had malfunctioned by a rain barrel tipping over or developing a clogged outlet; or a rain garden overflowing or its flora removed by herbivores. To date, we have received no complaints from citizens equipped with rain barrels and rain gardens, and our own periodic observations indicate that none of the stormwater management practices have has malfunctioned. Preventative (synoptic surveys twice per year revealed opportunities for seasonal maintenance) or reactive (by request of a landowner) maintenance has been performed to keep the rain gardens and barrels in a reasonably high state of readiness. The provision of a “free” maintenance program to last the duration of the monitoring phase of the project was important for several reasons. First, we needed some assurance that the practices operated as designed so that practices were as effective as possible, and also it was imperative to maintain citizen morale and engagement to make ownership of the practices an attractive option and ensure that landowners saw these practices as rather easy to maintain. For example, early plant establishment was made difficult by drought conditions, and therefore more frequent watering and provision of replacement plants as needed were key factors in ensuring good establishment of plant materials in the first year, which led to very attractive plantings in the rain gardens in the next year.

Our work highlights a few aspects of rain barrel effectiveness and use that we had not expected. In its intended configuration, the rain barrel sits between the roof gutter downspout and accumulates rooftop runoff volume until its capacity is depleted, then runoff overflows to the storm drain. If the barrel drain is closed and the barrel is allowed to fill (and overflow), the stored water is available for later use by the landowner for domestic purposes (e.g., water plants, etc.). Due to variability in homeowner preferences, even the nominal detention is not reliably available as not all barrels are routinely drained, so successive rain fall is passed on as overflow. Yet, we have found in a growing number of parcels where rain barrels were adopted, the landowner leaves the barrel drain open and routes storm runoff to pervious lawn surfaces, or - if so equipped - to their rain garden. This arrangement therefore disconnects residential impervious area from the municipal stormwater system. In terms of routing stormwflow, the barrel can potentially store a finite amount of volume, but for the cases where the landowner has re-routed stormflow, the rain barrel is largely a pass-through. For the microcatchment in Figure 3, rain barrels were generally linked to the rain garden of residential pervious surface, accounting for about 0.0018 ha of drained area. The small amount of area drained by rain barrels and their intermediary role in stormflow routing placed any observable impacts due to rain barrels alone below the sensitivity of our model. However, there appears to be less-tangible and non-structural benefits to small scale detention through rain barrel deployment. We are interested in better understanding how rain barrels may be a potentially effective approach to initially engaging citizens in their new role as a stormwater manager. Deployment of rain barrels may be a good first step in the phased recruitment of citizen stormwater managers that would eventually lead to installation of rain gardens, larger cisterns, green roofs, etc. in a broader program of decentralized stormwater management.

Although the rain garden operates year around and apparently maintains its design detention capacity across the seasons, the rain barrels are taken out of action for the cold season (typically November – March). This is accomplished in one of two ways: the barrel is either flipped over and the downspout is allowed to flow into the storm sewer inlet, or the downspout is extended and permitted to freely flow onto the lawn or into a rain garden. Alternately, the rain barrel is left in place with the drain open, and any stormflow (or snow melt volume) into the barrel passes through the drain orifice to the storm drain inlet, or conveyed to pervious surface or a rain garden through a flow spreader across the landscape or routed with a hose. Even though rain gardens typically have less storage capacity due to the near-saturation soil moisture conditions in the wet, cold season; we do understand from the lack of complaints that there have been no rain garden overflows. This would suggest that we disconnection of impervious surfaces is retained year-round. Given all of the options and how these are administered by the landowner, we have been left with a variety of routing schemes for stormwater runoff. Due to limited access to private property during the year, we have not been able to fully catalogue the specific approaches.

The proactive routing of stormwater runoff subtracts from storm sewer pipeflow by literally taking the excess stormwater flow from a given parcel out of the formal stormwater drainage infrastructure. If we assume that each of these residences routed all of their runoff to the rain garden and rain barrels in the warm season, our coarse modeling exercise suggests that detention is implemented densely enough to effect decreased stormwater quantity (relative to pre-management conditions) at the scale of a neighborhood stormwater outfall (Figure 4).

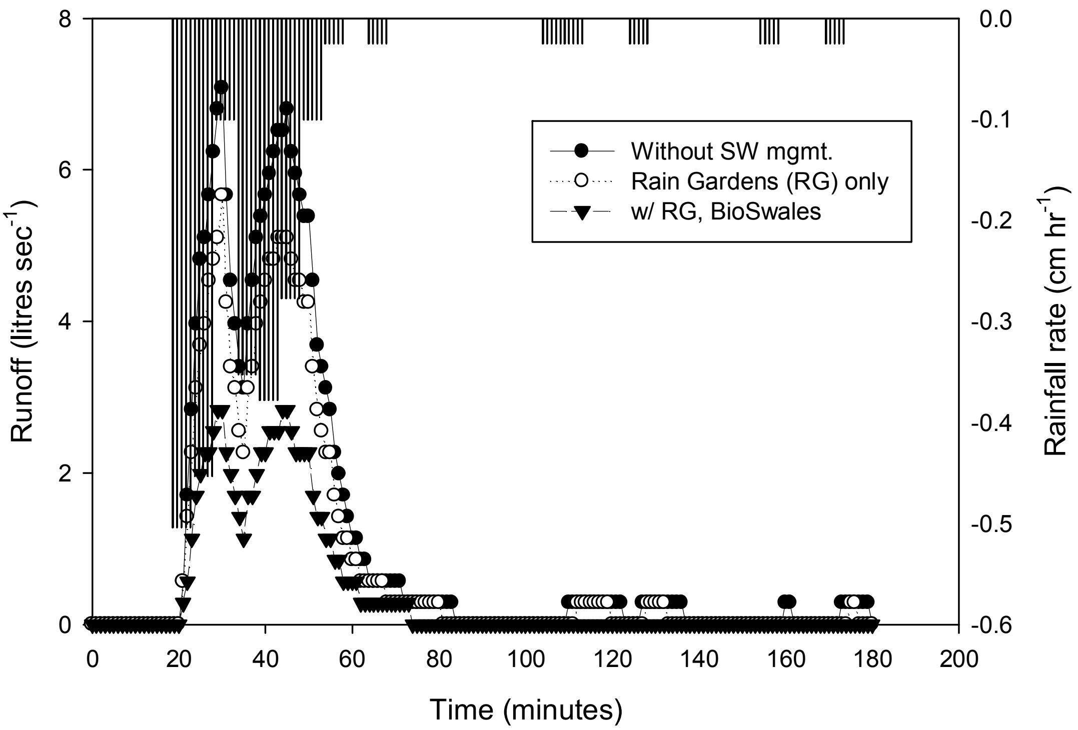

Figure 4. Hydrographs show catchment response without stormwater management, then with rain gardens and rain barrels deployed via the auction effort, and finally an anticipatory look at response given both rain gardens and bioswales implemented in the public right-of-way. The light, relatively frequent rain event is chronicled in the grey vertical bars and occurred on June 26 2008, wherein approx. 0.25 cm rainfall fell over the course of three hours.

Our analysis indicates that the hydrograph without stormwater management practices follows the rainfall pattern closely. This is very likely due to the predominant role of the street surface as directly-connected impervious area, providing the predominant contribution to total runoff production in this very small catchment. However, once a total of eleven rain gardens are installed, these parcels no longer contribute runoff volume to the outlet, and there is a modest decrease in stormwater volume (Figure 4) peaks. Yet, the hydrograph retains the shape of the hyetograph, and indicates that the rainfall-runoff dynamic of the catchment is still dominated by the roadway. This suggests that the next step in this stormwater mitigation process is to address roadway runoff though incentives directed at adding detention to public right-of-way, which is nominally managed by the local municipal government. We offer a prognostic view of the storm hydrograph if rain gardens are maintained and bioswales along the public right-of-way are implemented for additional detention capacity. The combined impact of rain gardens and bioswales is projected to be substantial, as the hydrograph peaks have not only leveled off, but the detention has also started to affect the time domain of runoff response through storage of what otherwise would have been direct runoff routed to the outlet (Figure 4); and the small amounts of rainfall towards the end of the event have been completely absorbed.

4 CONCLUSIONS

A decentralized, retrofit approach to storm water management was implemented in a small suburban drainage on the basis of a voluntary reverse auction. The campaign led to the installation of 83 rain gardens and 176 rain barrels on approximately 20 percent of 350 residential properties in the watershed, and a microcatchment showed relatively high (~50%) adoption with eleven rain gardens and 16 rain barrels spread across 29 residences. The density of this implementation impacted catchment hydrology by volume reduction for a small rainfall event, though there was no shift in time domain of the runoff hydrograph due to the predominance of a roadway that produced the majority of direct runoff. Therefore, the auction approach implemented stormwater management into private properties within a micro-catchment and at a density projected to be sufficient in scale to reduce some of the total storm volume for a light storm event. To achieve a greater degree of detention and stormflow quantity reduction, a different set of incentives would need to be aimed at the municipal level. We suggest that infiltrative bioswales placed in the public right-of-way alongside a road would be potentially effective at further reductions in stormflow volume and starting to flatten storm hydrograph peaks over the course of the storm. Rain barrels are noted for their potential to act as a recruitment tool with ancillary benefits for residential landowners.

LIST OF REFERENCES

Booth, D.B. and Jackson, C.R.(1997). Urbanization of aquatics – degradation thresholds, stormwater detention, and limits of mitigation, J. Am. Water Res. Assoc., 33, 1077-1090.

Gilroy, K.L., McCuen, R.H. (2009). Spatio-temporal effects of low impact development practices. J. Hydrology, 367, 228-236.

Green, R.H. (1993). Application of repeated measures designs in environmental impact and monitoring stuides. Australian J. Ecol., 18, 81-98.

Parikh, P., Taylor, M., Hoagland, T., Thurston, H. and Shuster, W. (2005). Application of market mechanisms and incentives to reduce stormwater runoff: an integrated hydrologic, economic, and legal approach. Env. Sci. Policy, 8, 133-144.

Roy, A.H and Shuster, W.D. (2009). Unraveling urban drainages for watershed management: applications of impervious surface connectivity data. 2009. AH Roy* and WD Shuster. J. Am. Water Resourc. Assoc., Volume 45 Issue 1, 198 – 209.

Shuster, W.D, Gehring, R, and Gerken, J. (2007) Prospects for enhanced groundwater recharge via infiltration of urban stormwater runoff – a case study. J. Soil Water Conservation 62, 129-137.

Thurston, H., Roy, A., Shuster, W.D., Cabezas, H., Morrison, M., and Taylor, M.A. (2008). Using Economic Incentives to Manage Stormwater Runoff in the Shepherd Creek Watershed, Part I. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/129.

Vaes, G., Berlamont, J. (2001). The effect of rainwater storage tanks on design storms. Urban Water, 3, 303-307.

Villareal, E. L., and Bengtsson, A.S.D.L. (2004). Inner city stormwater control using a combination of best management practices. Ecol. Eng., 22, 279-298.